Bitcoin, Blockchains and Efficient Distributed Spacecraft Mission Control

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GSFC IS&T Colloquium

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Cryptocurrency Basics

- Store value
- Build ecosystem to enable efficient distribution and management of value
  - ✓ **Original Blockchain Organizations**: Bitcoin, Litecoin, Ethereum, primarily interested in maintaining the base infrastructure that keeps the blockchain operating as is (or part of a roadmap). Primarily focused on the infrastructure necessary for the cryptocurrency operating smoothly
  - ✓ **Decentralized Services on Top of Blockchain -** e.g Cosmos – an Internet of blockchains, Swarm – decentralized crowdfunding, Storj – distributed encrypted blockchain based , open source, cloud storage, or blockchain stacks using multiple blockchain services
  - ✓ **Enterprise Blockchain Organizations -**These include organizations like Ripple, Ethereum Enterprise Alliance and Hyperledger.
    - Purpose is to take public blockchain technology and figure out how to make it 'work' for current enterprise organizations.
    - While some goals are in alignment with the public blockchain goals, specific use cases will turn enterprise blockchain into a classification of its own. This means we need to consider the Enterprise use cases as separate entities

Cryptocurrency Basics

- ✓ **Entrepreneurial Ventures utilizing Blockchain**
  - These are start-ups and businesses not focused on infrastructure, but building services to utilize blockchain technology.
  - Current exchanges (such as Coinbase) as well as companies working inside Consensys would be an example of this (check out VariabL, a Decentralized Options Market). These are guys that are building services outside of the blockchain to make it more useful.
  - As time goes on, this group will grow dramatically as the underlying technology gets more mature.
- Blockchain to manage space applications
  - ✓ Value is services capacity e.g. downlink capacity, imaging capacity, power capacity, ground networks for distribution etc
  - ✓ any limited resource

Source: https://www.quora.com/As-of-early-2017-what-is-a-summary-of-the-cryptocurrency-ecosystem

Cryptocurrency Recent News

- As of September 6, 2017, cryptocurrency market capitalization was $157 billion compared to $12 billion Sept 12, 2016 (source: https://coinmarketcap.com/charts/)
- Trading volume for all cryptocurrencies was recently $5 - $9 billion USD per 24 hour period versus $112 million Sept 12, 2016 (source: https://coinmarketcap.com/charts/)
- Market capitalization climbed 17% from Sept 5, 2017, $20 billion in 24 hours, recovering from 25% decline earlier in week
  - ✓ China's financial regulators deemed illegal, initial coin offerings (ICO), or sale of new cryptocurrencies to fund blockchain project development
- Van Eck (24.7 billion money manager) filed with SEC to start an ETF based on Bitcoin linked derivatives on Aug 11, 2017 (going more mainsteam)
- Previously SEC shot down Cameron and Tyler Winklevoss' (Facebook, ConnectU) request for a bitcoin ETF listing on Bats, the stock exchange recently purchased by exchange giant CBOE Holdings, in March.

Five of Top Crypto-Currencies

Crypto	Key Functions	Basic Unit	% market Sept 12, 2016	% market Sept 12, 2017	% price increase since 1/1/2017	Comment
Bitcoin	Public blockchain, P2P transactions	bitcoin	80	47.5	451 (520 max approx.)	85% of market as recently as Mar 5, 2017
Ethereum	Smart Contracts	ether	8.22	19.08	3871 (5000 max)	
Neo	Chinese version of Ethereum	neo	0	0.72	15753 (33340 max)	
Litecoin	Faster transactions and improved storage requirements	Litoshi	1.5	2.38	1438 (1856 max)	
Ripple	Commercial Blockchain, speed, private P2P	XRP/ drops	1.72	5.6	3505 (5960 max)	

Source: https://coinmarketcap.com/charts/

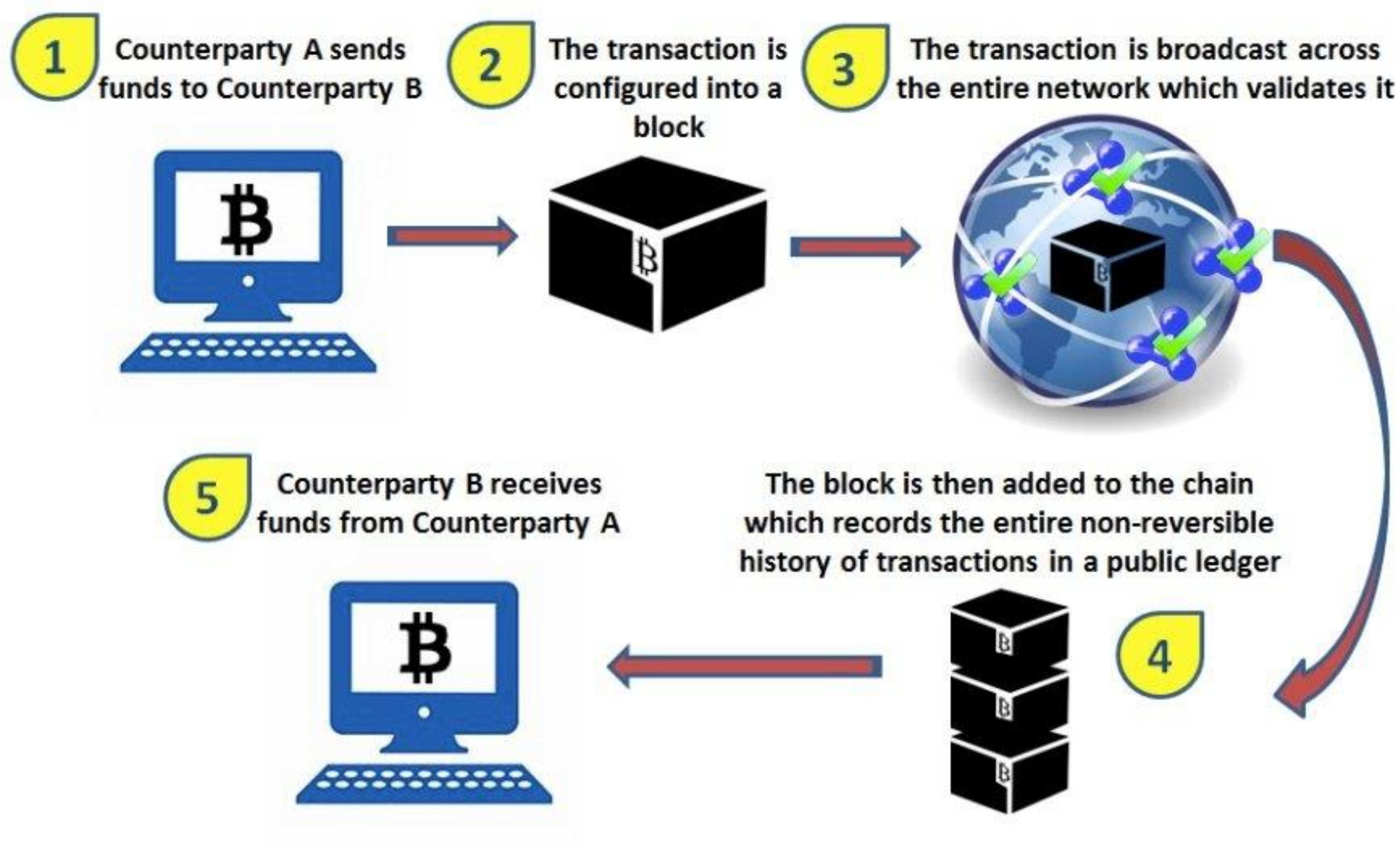
Distributed Spacecraft Mission Definition

- A Distributed Spacecraft Mission (DSM) is one that involves multiple spacecrafts to achieve one or more common goals.
- If defined from inception, then it is called a “constellation”
- If it becomes a DSM after the fact, then it is called an “ad hoc” DSM or “virtual mission”

from GSFC internal report by Jacqueline LeMoigne

Basics of Bitcoin

Exhibit 1: The Blockchain is a distributed, public ledger, most commonly known as the core underlying technology for Bitcoin



1 Counterparty A sends funds to Counterparty B

2 The transaction is configured into a block

3 The transaction is broadcast across the entire network which validates it

4 The block is then added to the chain which records the entire non-reversible history of transactions in a public ledger

5 Counterparty B receives funds from Counterparty A

Source: Goldman Sachs Global Investment Research.

Key Bitcoin Characteristics

- Distributed ledger (stored in blockchain)
- Easy to set up and participate (low entry barrier)
- Anonymous (public access)
- Transparent, holographic, provenance, audit trail, trust, collaboration
- Minimizes transaction fees (very low cost)
- Fast (payments arrive in minutes) versus international banking delays
- Non-repudiable, immutable, encrypted

Benefits for DSM Use

- Lowers cost
- Increases reliability
- Reduces cost to join constellation since all that is needed is blockchain interface (similar to automotive Onboard Diagnostics (OBD II) standards)
- Automatic audit trail
  - ✓ Provides data provenance
  - ✓ Great tool for debugging (similar to automotive Onboard Diagnostics (OBD II) standards)
  - ✓ Provide data for artificial intelligence tools
    - ❖ More and easy access to training data
    - ❖ Enables continuous learning because new data immediately and constantly comes in (perfect for Deep Learning/Tensor Flow)
  - ✓ Can document digital rights and therefore promotes sharing of data
    - ❖ People are willing to share their data in open space if data is protected and if Intellectual Property rights protected
  - ✓ Makes testing easier
- Enables easier and more automation at lower cost
  - Automatic resource outage alerts
  - Enables localized automated replanning (e.g. ground station out, replan for later downlink without ground as central coordination point, thus less efficient)
  - Enables constellation level model-based diagnostic tool similar to Livingstone created by Ames and run onboard Earth Observing 1 (also similar to OBD II but for constellations)

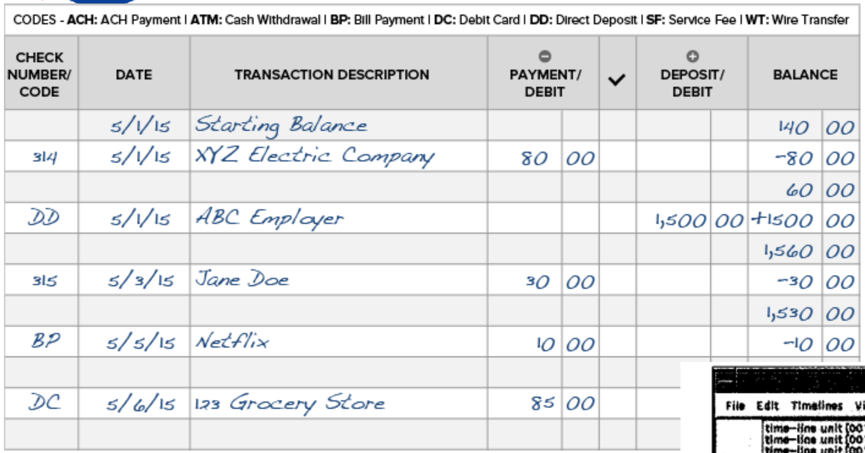
Problems to Solve for DSM Use

- Standard blockchains used for Bitcoin are slow
  - ✓Transactions validated in blocks every 10 minutes
- Blockchain file sizes are very large and the initial download can take 24-48 hours on Bitcoin
- Concurrency issues
- Need light, hardened version similar to what was done for the Core Flight Software package to use on spacecrafts

Private Blockchain (Ripple and others)

- Limited user base
- Users need permission
- Transactions verification different – centralized verification system
- Faster
- More efficient with data storage
- Augmented with commercial distributed databases to enhance performance

Ledgers

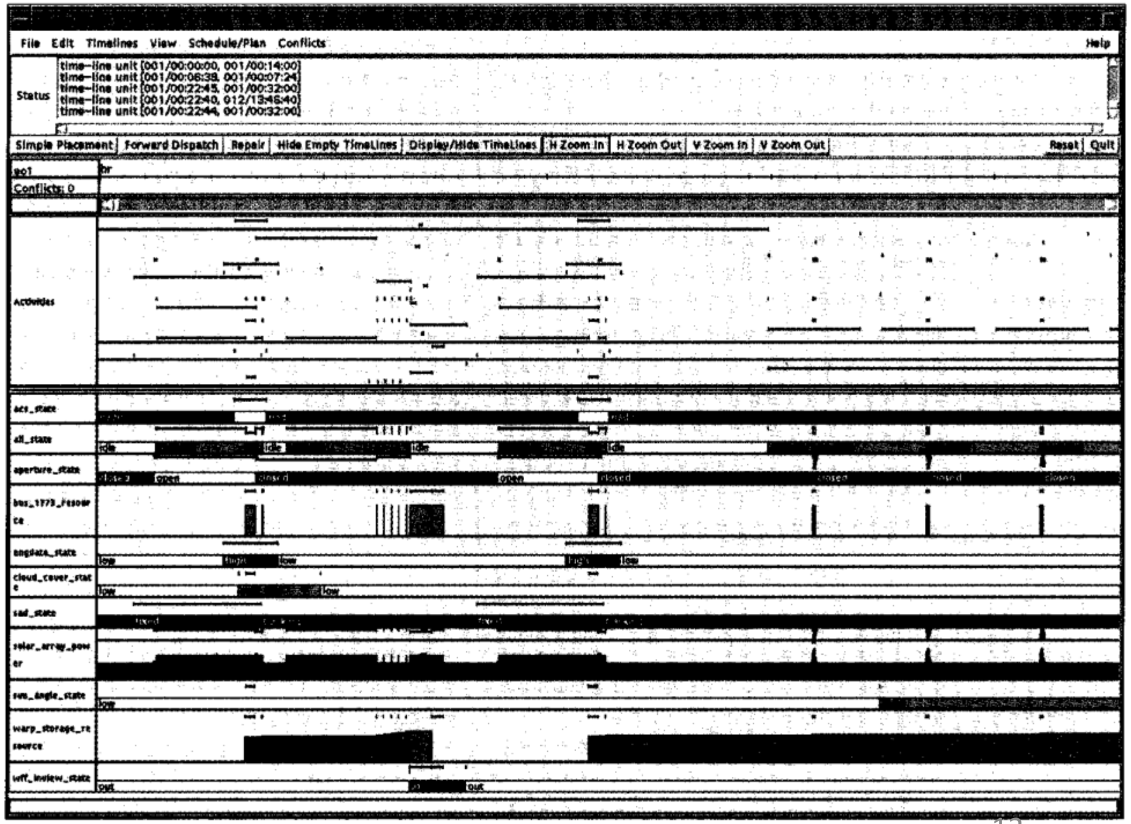


CODES - **ACH:** ACH Payment I **ATM:** Cash Withdrawal I **BP:** Bill Payment I **DC:** Debit Card I **DD:** Direct Deposit I **SF:** Service Fee I **WT:** Wire Transfer

CHECK NUMBER/ CODE	DATE	TRANSACTION DESCRIPTION	⊖ PAYMENT/ DEBIT		✓	⊕ DEPOSIT/ DEBIT		BALANCE	
	5/1/15	Starting Balance						140	00
314	5/1/15	XYZ Electric Company	80	00				-80	00
								60	00
DD	5/1/15	ABC Employer				1,500	00	+1500	00
								1,560	00
315	5/3/15	Jane Doe	30	00				-30	00
								1,530	00
BP	5/5/15	Netflix	10	00				-10	00
DC	5/6/15	123 Grocery Store	85	00					

- Example of checkbook ledger where someone keeps track of their spending transactions
- Key issue: checks validated and cleared

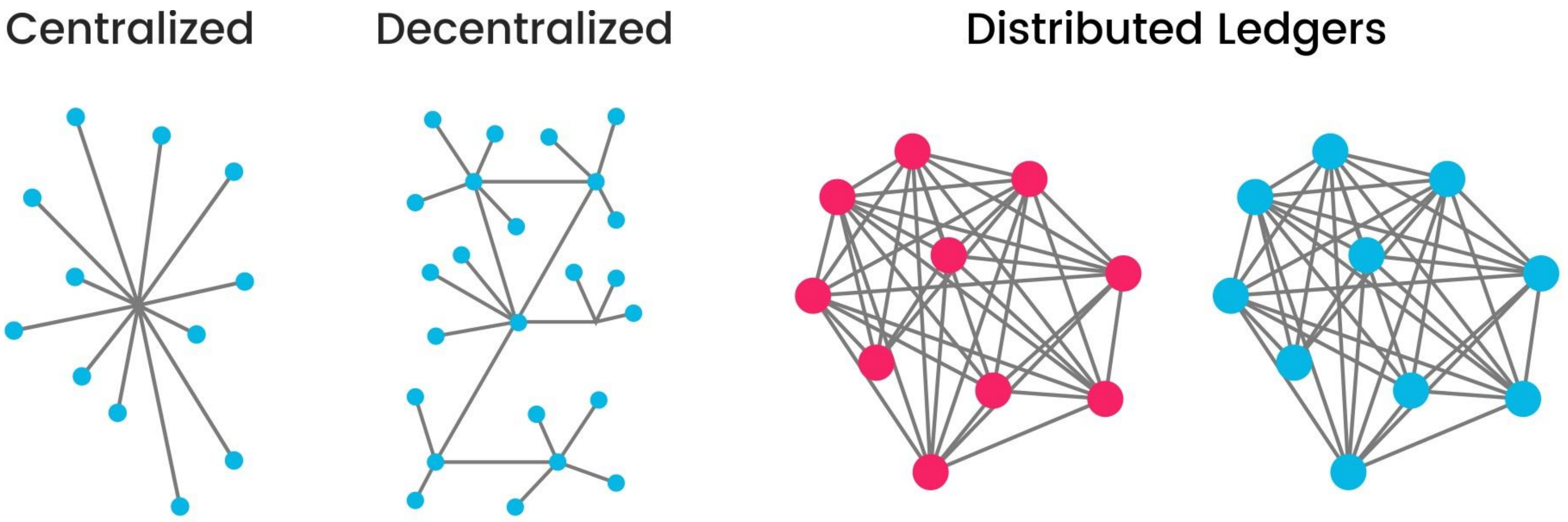
- Example of EO-1 Activity Plan which kept track of operation activities and acted as localized ledger
- Key issue: Interim and End-Item verification (partial list)
  - Did image goals get uploaded
  - Did image get taken
  - Did image data get downlinked to ground station
  - Did ground station successfully receive downlink and forward
  - Did Data Processing System successfully process to Lev0, Lev1
  - Did image get published or sent to user



time-line unit [001/00:00:00, 001/00:14:00]
time-line unit [001/00:06:38, 001/00:07:24]
time-line unit [001/00:22:45, 001/00:32:00]
time-line unit [001/00:22:40, 012/13:46:40]
time-line unit [001/00:22:44, 001/00:32:00]

Figure 1. A one-week operations plan for the New Millennium Earth Orbiter One generated by the Aspen planning system.

Different Ledger Configurations



The New Networks

Distributed ledgers can be public or private and vary in their structure and size.

Public blockchains

Require computer processing power to confirm transactions (”mining”)

- Users (●) are anonymous

- Each user has a copy of the legder and partipates in confirming transactions independently

- Users (●) are not anonymous

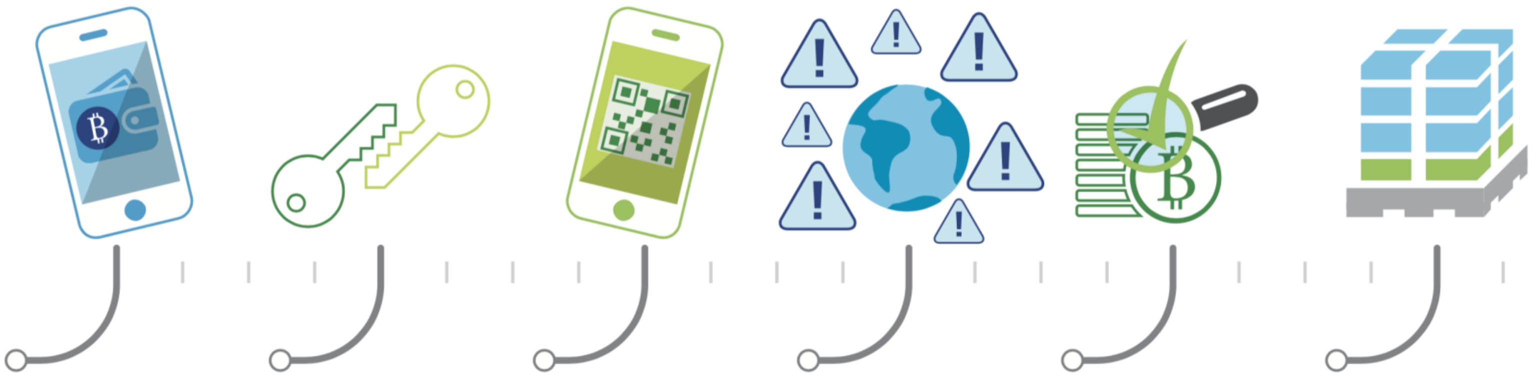
- Permision is required for users to have a copy of the legder and participate in confirming transactions

Blockgeeks

Most if not all spacecraft operations live here

Some Details

Figure 1. How the Bitcoin blockchain works



Bob owes Alice money for lunch. He installs an app on his smartphone to create a new Bitcoin wallet.
A wallet app is like a mobile banking app and a wallet is like a bank account.

To pay her, he needs two pieces of information: his private key and her public key.

Bob gets Alice's public key by scanning a QR code from her phone, or by having her email him the payment address, a string of seemingly random numbers and letters.*

The app alerts Bitcoin 'miners' around the world of the impending transaction. 'Miners' provide transaction verification services.

The miners verify that Bob has enough bitcoins to make the payment.

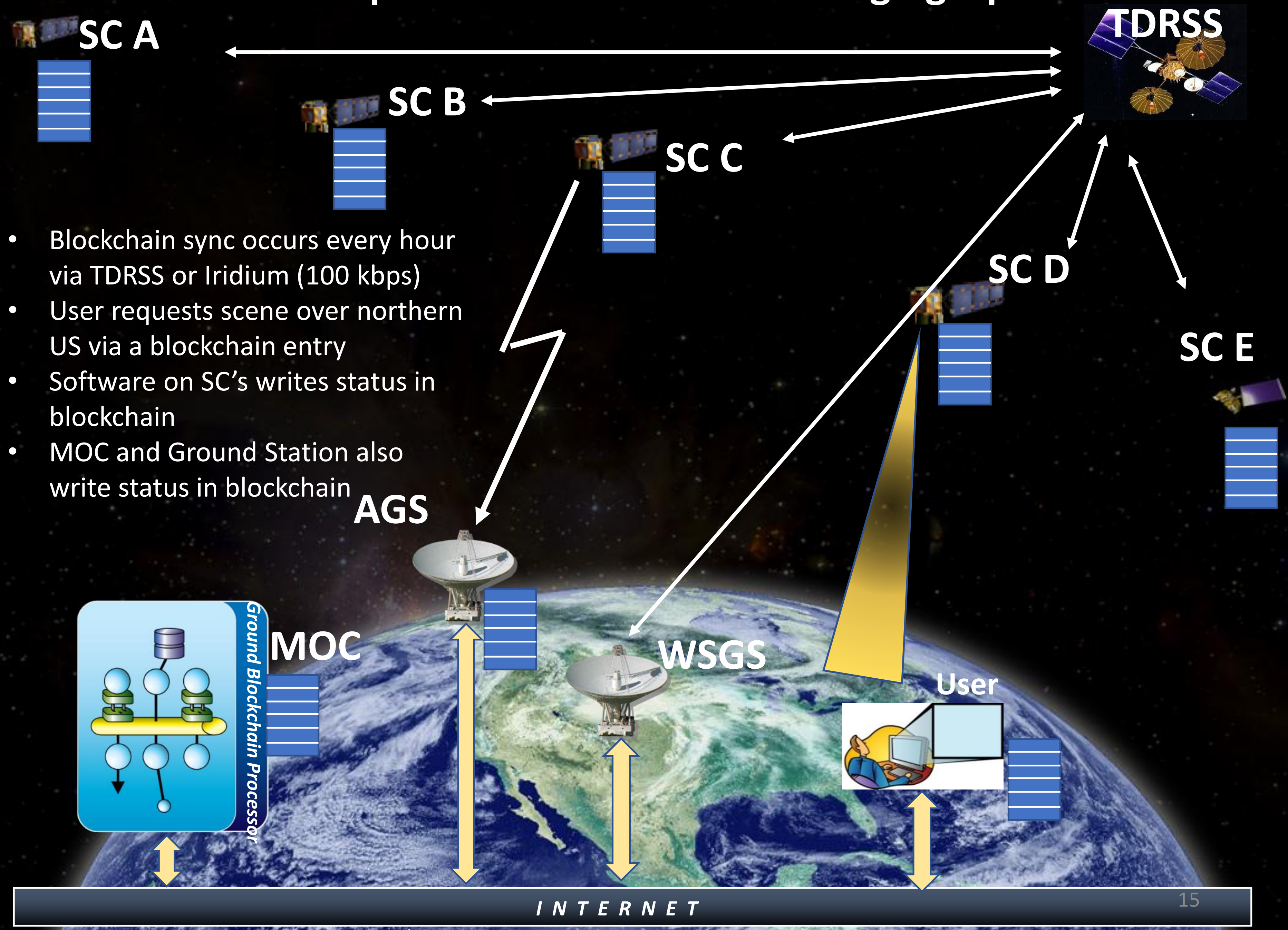
Many transactions occur in the network at any time. All the pending transactions in a given timeframe are grouped (in a block) for verification. Each block has a unique identifying number, creation time and reference to the previous block.

*Anyone who has a public key can send money to a Bitcoin address, but only a signature generated by the private key can release money from it.

Graphic: Deloitte University Press. Source: American Banker[20]

Blockchain in Space Scenario 1 – Basic Imaging Operations

- Blockchain sync occurs every hour via TDRSS or Iridium (100 kbps)
- User requests scene over northern US via a blockchain entry
- Software on SC's writes status in blockchain
- MOC and Ground Station also write status in blockchain



Basic Imaging Operations

- User enters image request, location and timeframe via blockchain entry
- Assets provide availability which includes overflight times, inview times for ground stations and prescheduled conflicts
- First available asset schedules image time and downlink time as needed
- Operation errors, outages etc. are recorded on blockchain
- Completion time, downlink time to ground station and successful publishing of data to user specified location are documented in blockchain.

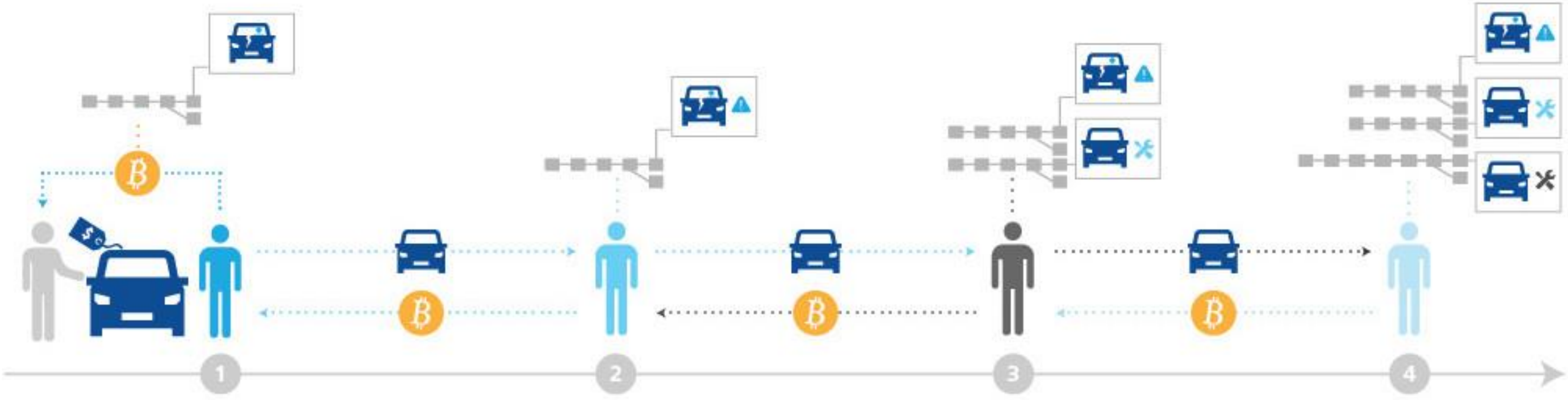
Smart Contracts (Ethereum and others)

- Autonomous
- Encryption allows safeguarding of documents
- Documents are backed up since many copies
- Low cost to execute since no intermediary
- Accurate because terms are executed via software directly from contract

Porting Operational Spacecraft Software to Distributed Smart Contracts

- Autonomous Sciencecraft Experiment (ASE) – onboard autonomy that ran on Earth Observing 1 (EO-1) for 12 years
- Livingstone Model-Based Onboard Diagnostic tool – ran on EO-1
- AMPS, ASPEN and other planning tools
- Augment all of the SensorWeb tools (https://sensorweb.nasa.gov)
- Accurate because terms are executed via software directly from contract

Smart Contract Example



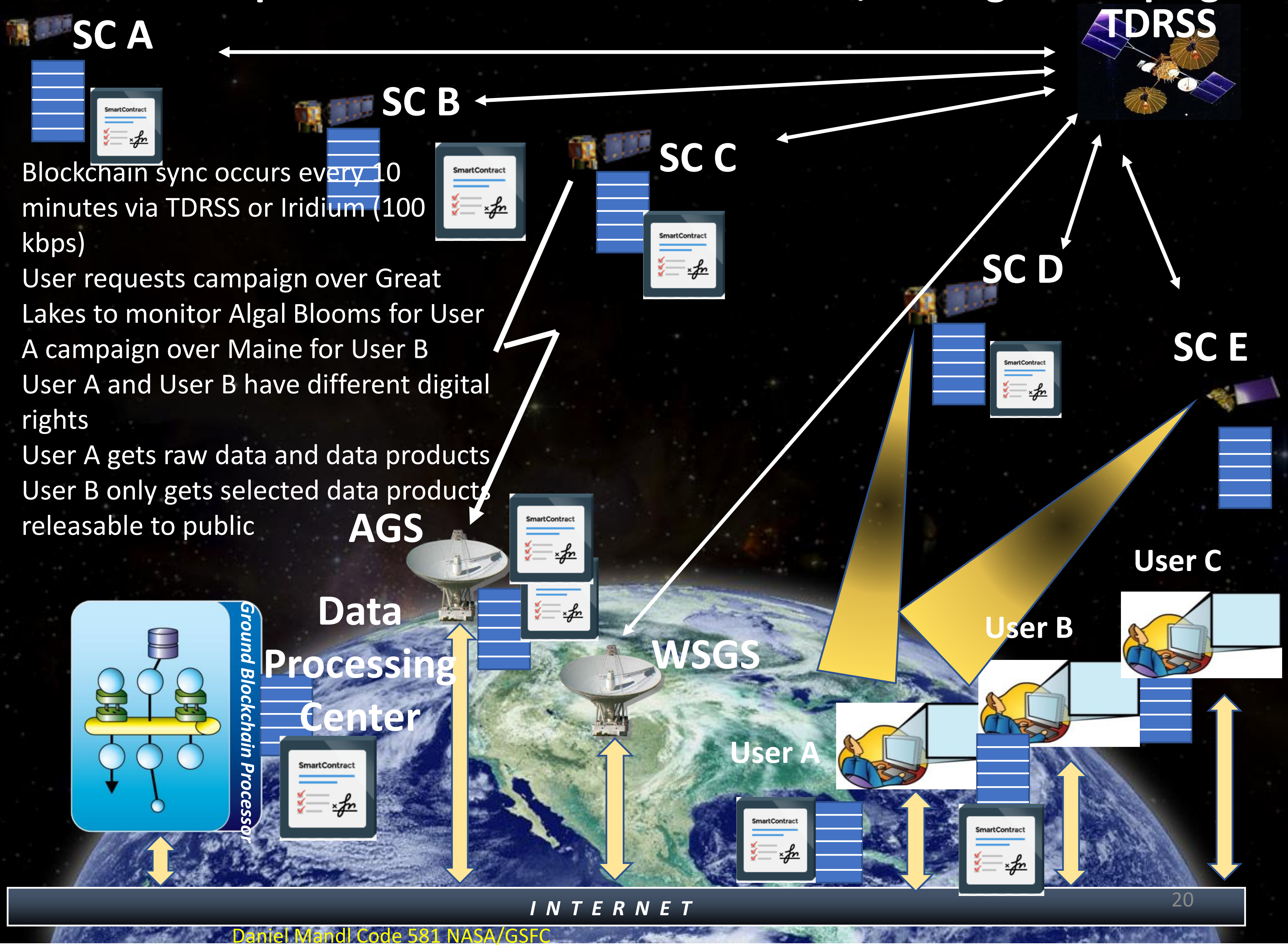
Person A
purchases a car from a dealer. That car is represented in the block chain by a bitcoin, allowing the purchaser to view the car's history in the public ledger.

Person B
purchases the car from Person A and learns the car was in an accident by reviewing the car's history in the block chain.

Person C
purchases the car from Person B and learns the car was serviced regularly and there was an accident by reviewing the car's history in the block chain.

Person D
purchases the car from Person C and reviews the car's history in the block chain to learn about the accident, service history, and recent work that was done on the car to pass an emissions test.

Blockchain in Space Scenario 2 – Smart Contract, Managed Campaigns



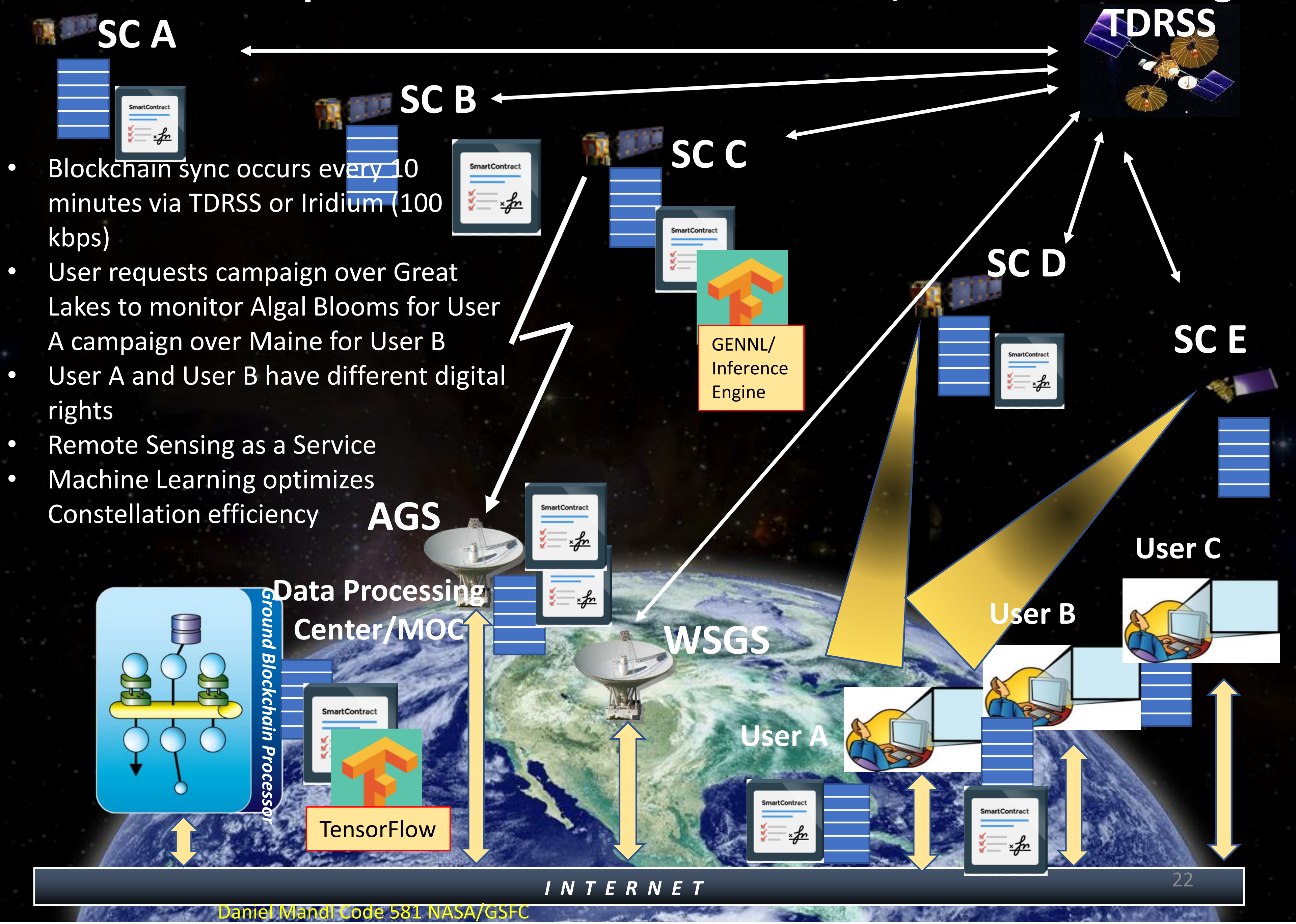
- Blockchain sync occurs every 10 minutes via TDRSS or Iridium (100 kbps)
- User requests campaign over Great Lakes to monitor Algal Blooms for User A campaign over Maine for User B
- User A and User B have different digital rights
- User A gets raw data and data products
- User B only gets selected data products releasable to public

Smart Contracts and Managed Campaigns

- Users submit smart contract to complete a series of images with conditions (e.g. weekly diurnal over a growing season spectral measurements to create time series)
- Assets self-schedule and route data and data products according to users depending on data rights
- Users provide backup imaging plans when assets are out of commission or failures occur
- Users provide time constraints and locations desired
- Audit trail of completed imaging operations with successes and failures documented in blockchain

Blockchain in Space Scenario 2 – Smart Contract, Machine Learning

- Blockchain sync occurs every 10 minutes via TDRSS or Iridium (100 kbps)
- User requests campaign over Great Lakes to monitor Algal Blooms for User A campaign over Maine for User B
- User A and User B have different digital rights
- Remote Sensing as a Service
- Machine Learning optimizes Constellation efficiency



Smart Contracts, Machine Learning to Optimize Constellation

- Users submit smart contract to complete a series of images with conditions (e.g. weekly diurnal over a growing season spectral measurements to create time series)
- Assets self-schedule and route data and data products according to users depending on data rights
- Machine learning allocated Constellation resources based on learned methods to optimize image output and minimize cost to user
- Users provide time constraints and locations desired
- Audit trail of completed imaging operations with successes and failures documented in blockchain
- Machine learning uses audit trail to continuously learn and improve
  - E.g Experiment being conducted (Ichoku, Mackinnon, Mandl et al) to observe fires and recognize their radiative type from any angle similar to recognizing a face at any angle

Blockchains for Artificial Intelligence

- Decentralized and Shared control encouraging data sharing
  - ➢ More data and better models
  - ➢ Qualitatively new data and therefore qualitatively new models
  - ➢ Shared control of AI training data and training models

➢ Immutability/audit trail

- ➢ Leads to provenance on training/testing data and models to improve the trustworthiness of the data and models

➢ Native assets/exchanges

- ➢ Leads to **training/testing data & models as intellectual property (IP)** assets, which leads to **decentralized data & model exchanges**. It also gives better control for upstream usage of your data

From: Blockchains for Artificial Intelligence
https://blog.bigchaindb.com/blockchains-for-artificial-intelligence-ec63b0284984

Application Areas for Earth Science

- Low latency operational coordination and dynamic tasking
  - Permission private block chain
  - Support SensorWeb with reduced decision latency
  - Coordinate action without exposing to risk of corruption
- Science mission coordination in Sensor Webs
  - Platforms within SensorWeb shared across diverse set of scientific missions
  - Private ledger will schedule for the various teams and have assurance of identify, access and prevent disruptive use of the instrument
- Distributed Data and Analysis
  - Portions anad copies of particular datasets scattered across public and private cloud computing environment
  - Provide record of location
  - Grant and revoke access permissions
  - Provide record of derived data
- Citizen Science
  - Collaborative access to science data
- Management of the Commons
  - Community aligns on a shared interest but cannot establish reciprocal trust between member
  - E.g. Avoiding orbital collisions

Source: AIST Blockchain Study for NASA HQ

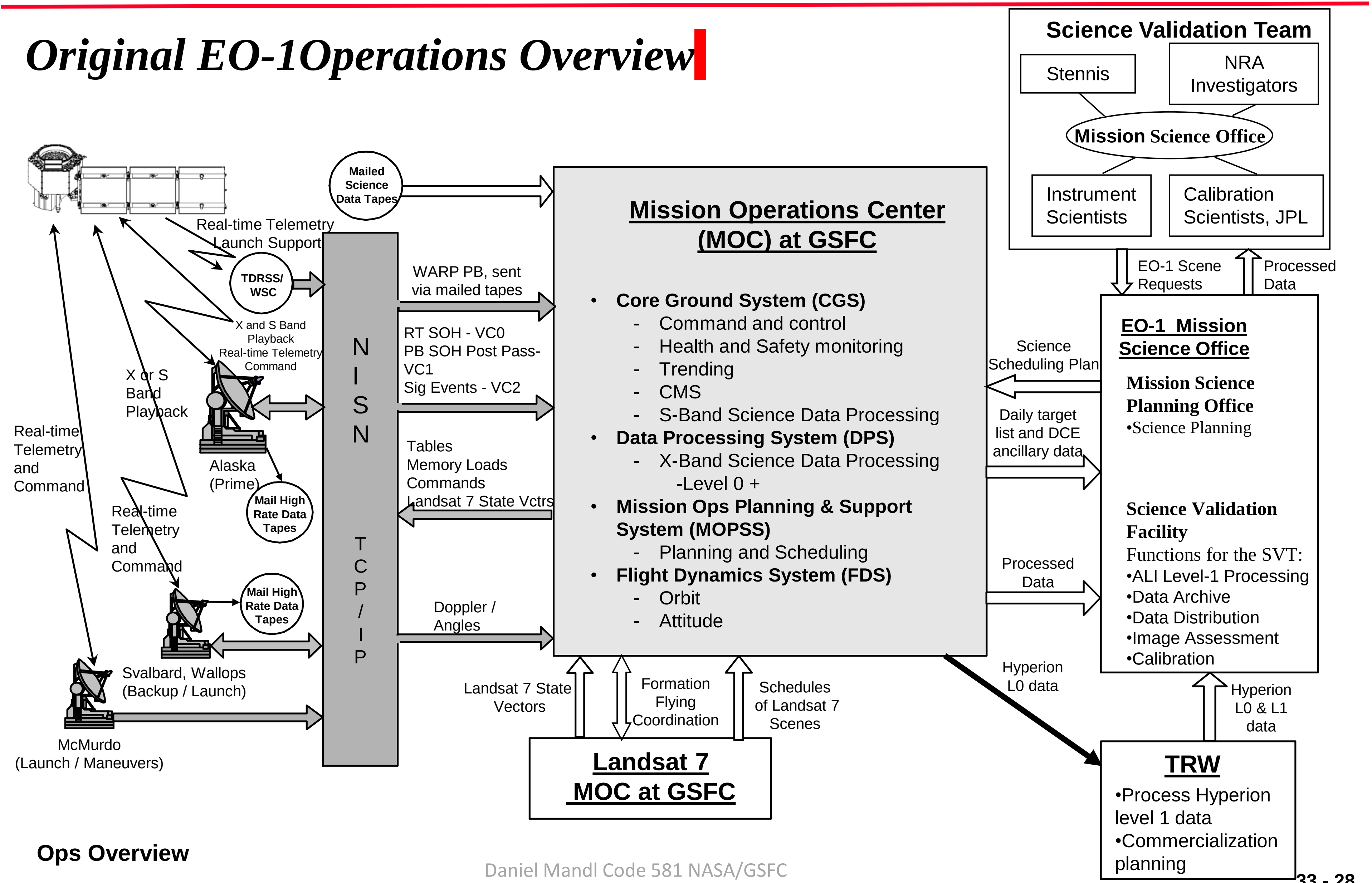
Related Issues to Blockchain in Space

- Delay Tolerant Network (DTN)
- Consultative Committee for Space Data Systems (CCSDS)

BACKUP

It's Complicated—Lot's of systems, pipes and delays!

Original EO-1Operations Overview



Science Validation Team

Stennis

NRA Investigators

Mission Science Office

Instrument Scientists

Calibration Scientists, JPL

EO-1 Scene Requests

Processed Data

EO-1 Mission Science Office

Mission Science Planning Office

•Science Planning

Science Validation Facility

Functions for the SVT:

•ALI Level-1 Processing
•Data Archive
•Data Distribution
•Image Assessment
•Calibration

Science Scheduling Plan

Daily target list and DCE ancillary data

Processed Data

Hyperion L0 data

Hyperion L0 & L1 data

TRW

•Process Hyperion level 1 data
•Commercialization planning

Mission Operations Center (MOC) at GSFC

- **Core Ground System (CGS)**
  - Command and control
  - Health and Safety monitoring
  - Trending
  - CMS
  - S-Band Science Data Processing
- **Data Processing System (DPS)**
  - X-Band Science Data Processing -Level 0 +
- **Mission Ops Planning & Support System (MOPSS)**
  - Planning and Scheduling
- **Flight Dynamics System (FDS)**
  - Orbit
  - Attitude

Landsat 7 State Vectors

Formation Flying Coordination

Schedules of Landsat 7 Scenes

Landsat 7 MOC at GSFC

Mailed Science Data Tapes

WARP PB, sent via mailed tapes

RT SOH - VC0
PB SOH Post Pass-VC1
Sig Events - VC2

Tables
Memory Loads
Commands
Landsat 7 State Vctrs

Doppler / Angles

NISN

TCP/IP

Real-time Telemetry
Launch Support

TDRSS/ WSC

X and S Band Playback
Real-time Telemetry
Command

X or S Band Playback

Alaska (Prime)

Mail High Rate Data Tapes

Real-time Telemetry and Command

Real-time Telemetry and Command

Mail High Rate Data Tapes

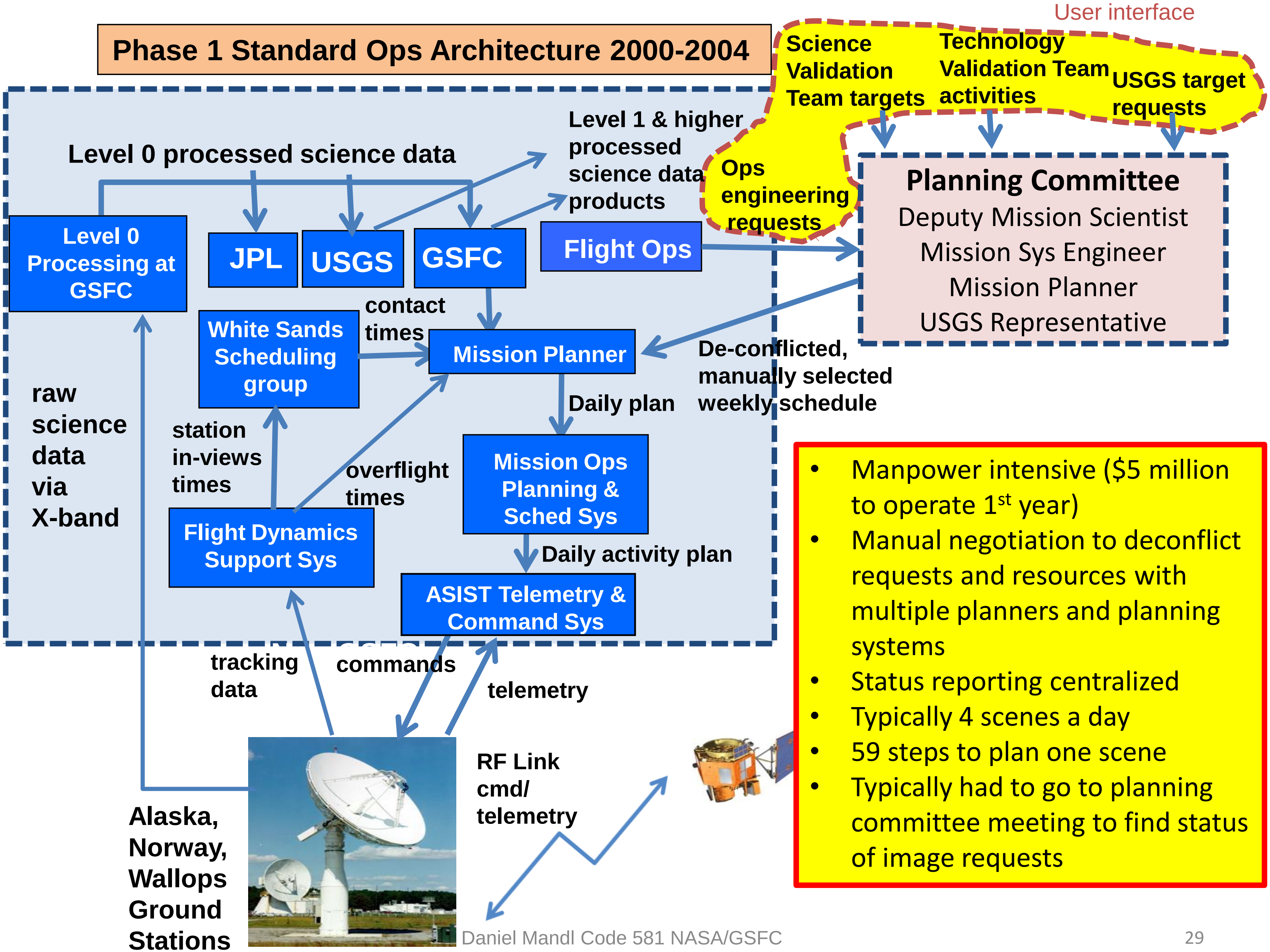
Svalbard, Wallops (Backup / Launch)

McMurdo (Launch / Maneuvers)

Ops Overview

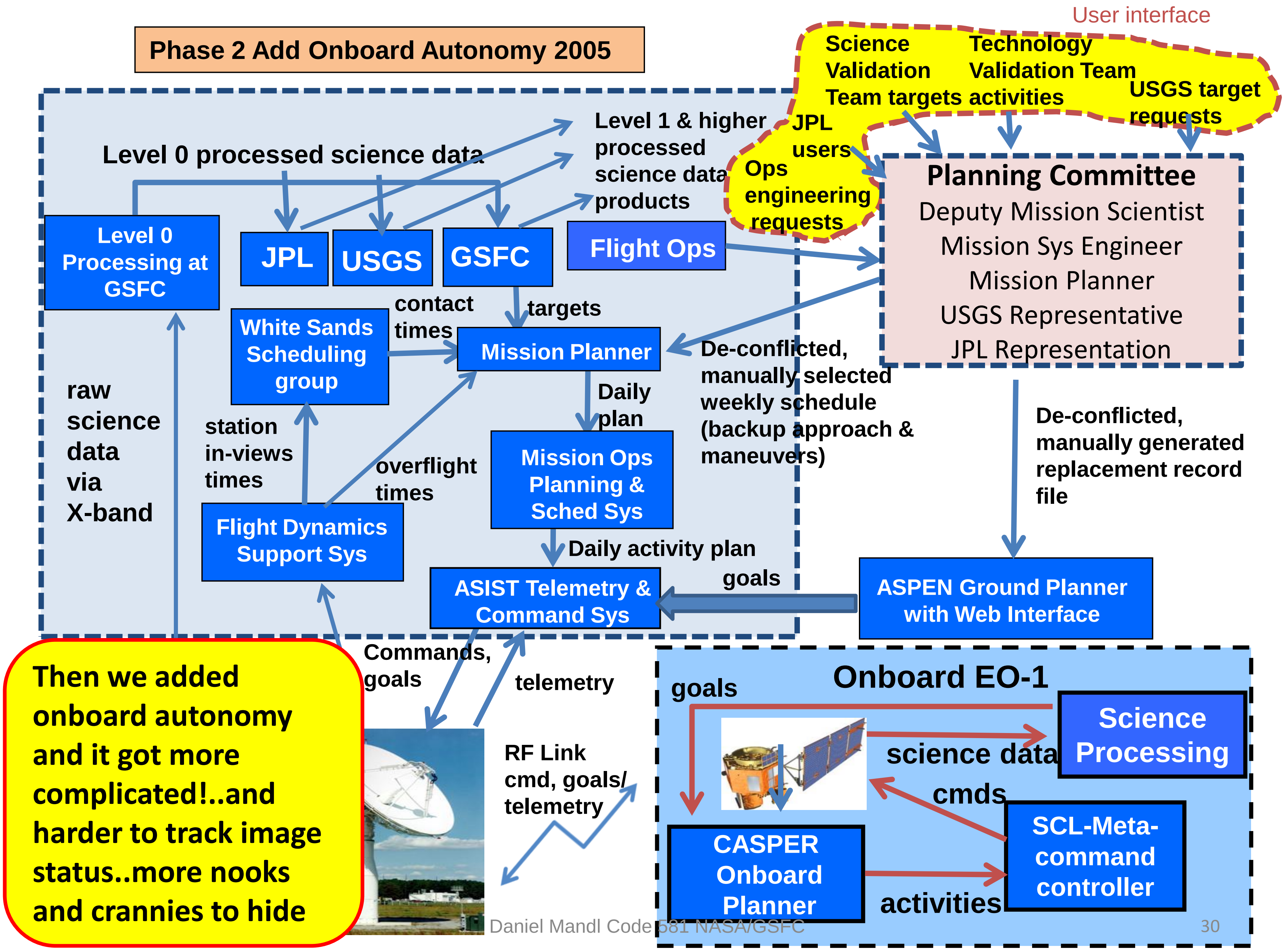
Day 4: 03/31/00

Phase 1 Standard Ops Architecture 2000-2004


User interface
Science Validation Team targets
Technology Validation Team activities
USGS target requests
Ops engineering requests
Planning Committee
Deputy Mission Scientist
Mission Sys Engineer
Mission Planner
USGS Representative
Level 0 processed science data
Level 1 & higher processed science data products
Level 0 Processing at GSFC
JPL
USGS
GSFC
Flight Ops
White Sands Scheduling group
contact times
Mission Planner
De-conflicted, manually selected weekly schedule
Daily plan
raw science data via X-band
station in-views times
overflight times
Mission Ops Planning & Sched Sys
Flight Dynamics Support Sys
Daily activity plan
ASIST Telemetry & Command Sys
tracking data
commands
telemetry
RF Link cmd/ telemetry
Alaska, Norway, Wallops Ground Stations

- Manpower intensive ($5 million to operate 1st year)
- Manual negotiation to deconflict requests and resources with multiple planners and planning systems
- Status reporting centralized
- Typically 4 scenes a day
- 59 steps to plan one scene
- Typically had to go to planning committee meeting to find status of image requests

Phase 2 Add Onboard Autonomy 2005


User interface
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USGS target requests
JPL users
Ops engineering requests
Planning Committee
Deputy Mission Scientist
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Mission Planner
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JPL Representation
Level 0 processed science data
Level 1 & higher processed science data products
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JPL
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targets
White Sands Scheduling group
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overflight times
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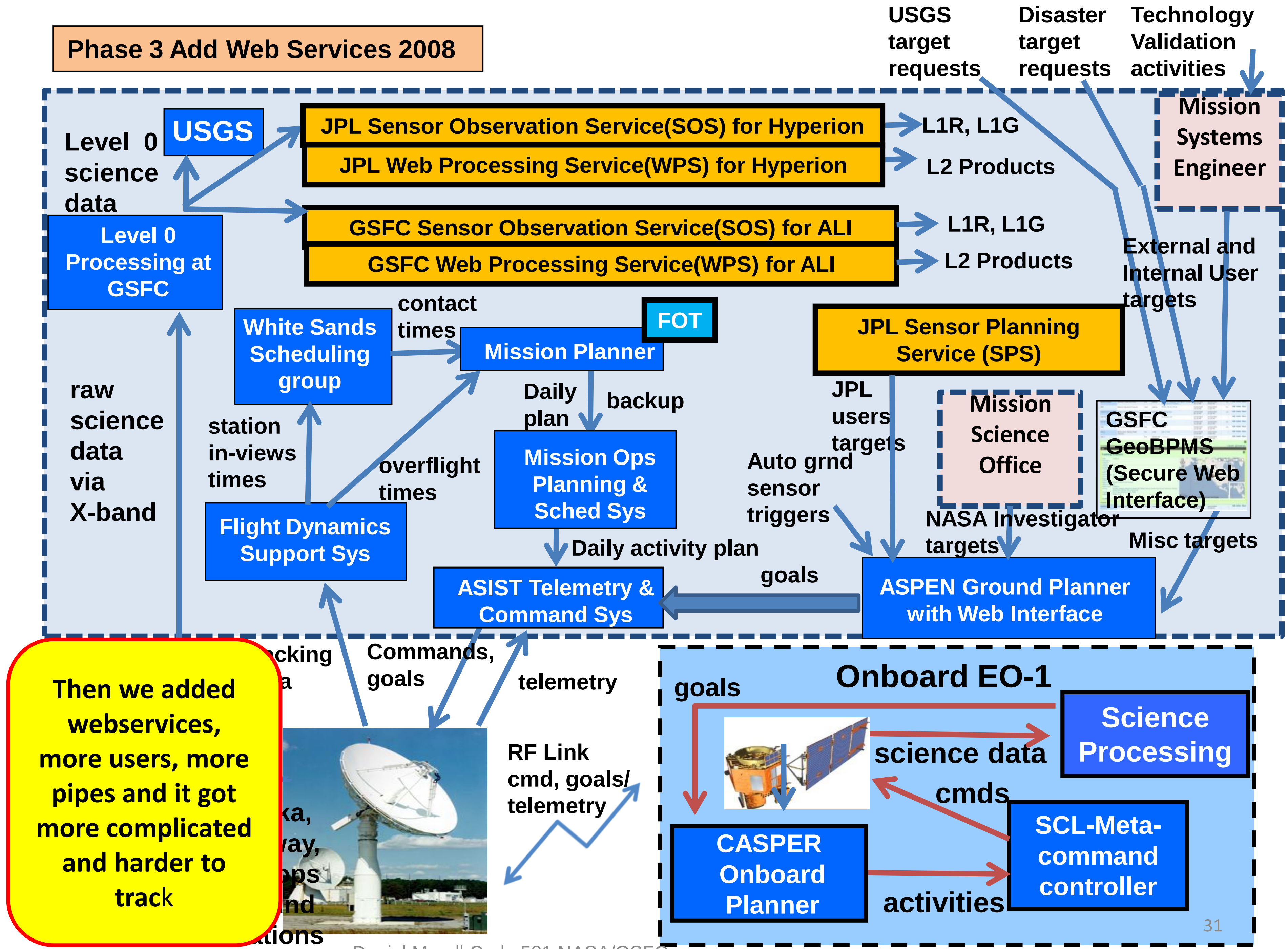
Flight Dynamics Support Sys
Daily activity plan
De-conflicted, manually generated replacement record file
goals
ASIST Telemetry & Command Sys
ASPEN Ground Planner with Web Interface
Commands, goals
telemetry
RF Link cmd, goals/ telemetry
Onboard EO-1
goals
Science Processing
science data
cmds
SCL-Meta-command controller
CASPER Onboard Planner
activities

Then we added onboard autonomy and it got more complicated!..and harder to track image status..more nooks and crannies to hide

Phase 3 Add Web Services 2008


USGS target requests
Disaster target requests
Technology Validation activities
Mission Systems Engineer
Level 0 science data
USGS
JPL Sensor Observation Service(SOS) for Hyperion
JPL Web Processing Service(WPS) for Hyperion
L1R, L1G
L2 Products
GSFC Sensor Observation Service(SOS) for ALI
GSFC Web Processing Service(WPS) for ALI
L1R, L1G
L2 Products
External and Internal User targets
Level 0 Processing at GSFC
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raw science data via X-band
station in-views times
overflight times
Daily plan
backup
Mission Ops Planning & Sched Sys
JPL users targets
Auto grnd sensor triggers
Mission Science Office
GSFC GeoBPMS (Secure Web Interface)
NASA Investigator targets
Misc targets
Flight Dynamics Support Sys
Daily activity plan
goals
ASIST Telemetry & Command Sys
ASPEN Ground Planner with Web Interface
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Commands, goals
telemetry
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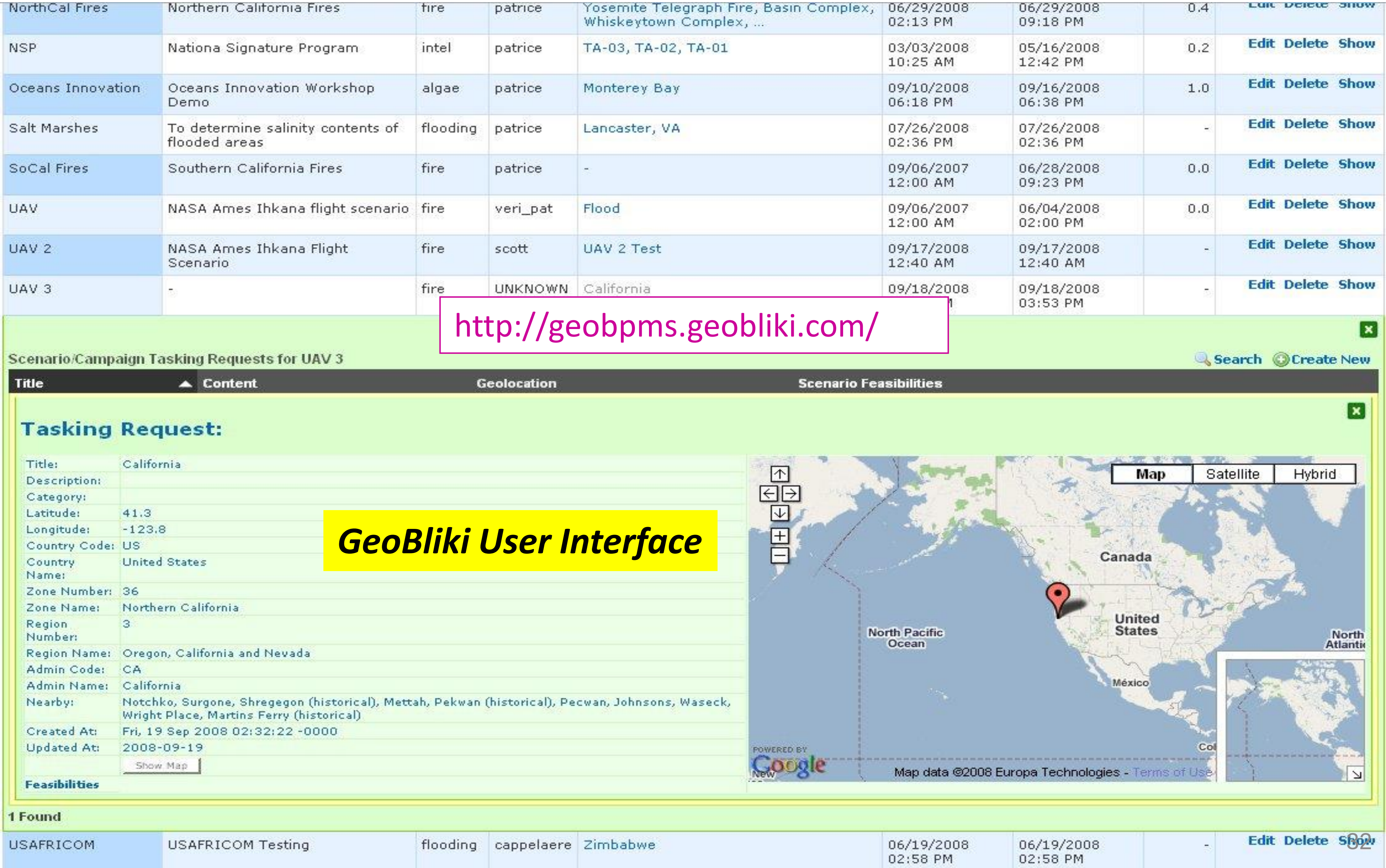
tions
RF Link cmd, goals/ telemetry
Onboard EO-1
goals
Science Processing
science data
cmds
CASPER Onboard Planner
activities
SCL-Meta-command controller

Then we added webservices, more users, more pipes and it got more complicated and harder to track

Built SensorWeb Tool - GeoBPMS-to Handle Complexity with Automated Web Notification and Tracking

Direct Internet Access to Data and Tasking



NorthCal Fires	Northern California Fires	fire	patrice	Yosemite Telegraph Fire, Basin Complex, Whiskeytown Complex, ...	06/29/2008 02:13 PM	06/29/2008 09:18 PM	0.4	Edit Delete Show
NSP	Nationa Signature Program	intel	patrice	TA-03, TA-02, TA-01	03/03/2008 10:25 AM	05/16/2008 12:42 PM	0.2	Edit Delete Show
Oceans Innovation	Oceans Innovation Workshop Demo	algae	patrice	Monterey Bay	09/10/2008 06:18 PM	09/16/2008 06:38 PM	1.0	Edit Delete Show
Salt Marshes	To determine salinity contents of flooded areas	flooding	patrice	Lancaster, VA	07/26/2008 02:36 PM	07/26/2008 02:36 PM	-	Edit Delete Show
SoCal Fires	Southern California Fires	fire	patrice	-	09/06/2007 12:00 AM	06/28/2008 09:23 PM	0.0	Edit Delete Show
UAV	NASA Ames Ihkana flight scenario	fire	veri_pat	Flood	09/06/2007 12:00 AM	06/04/2008 02:00 PM	0.0	Edit Delete Show
UAV 2	NASA Ames Ihkana Flight Scenario	fire	scott	UAV 2 Test	09/17/2008 12:40 AM	09/17/2008 12:40 AM	-	Edit Delete Show
UAV 3	-	fire	UNKNOWN	California	09/18/2008	09/18/2008 03:53 PM	-	Edit Delete Show

http://geobpms.geobliki.com/

Scenario/Campaign Tasking Requests for UAV 3

Title	Content	Geolocation	Scenario Feasibilities

Tasking Request:

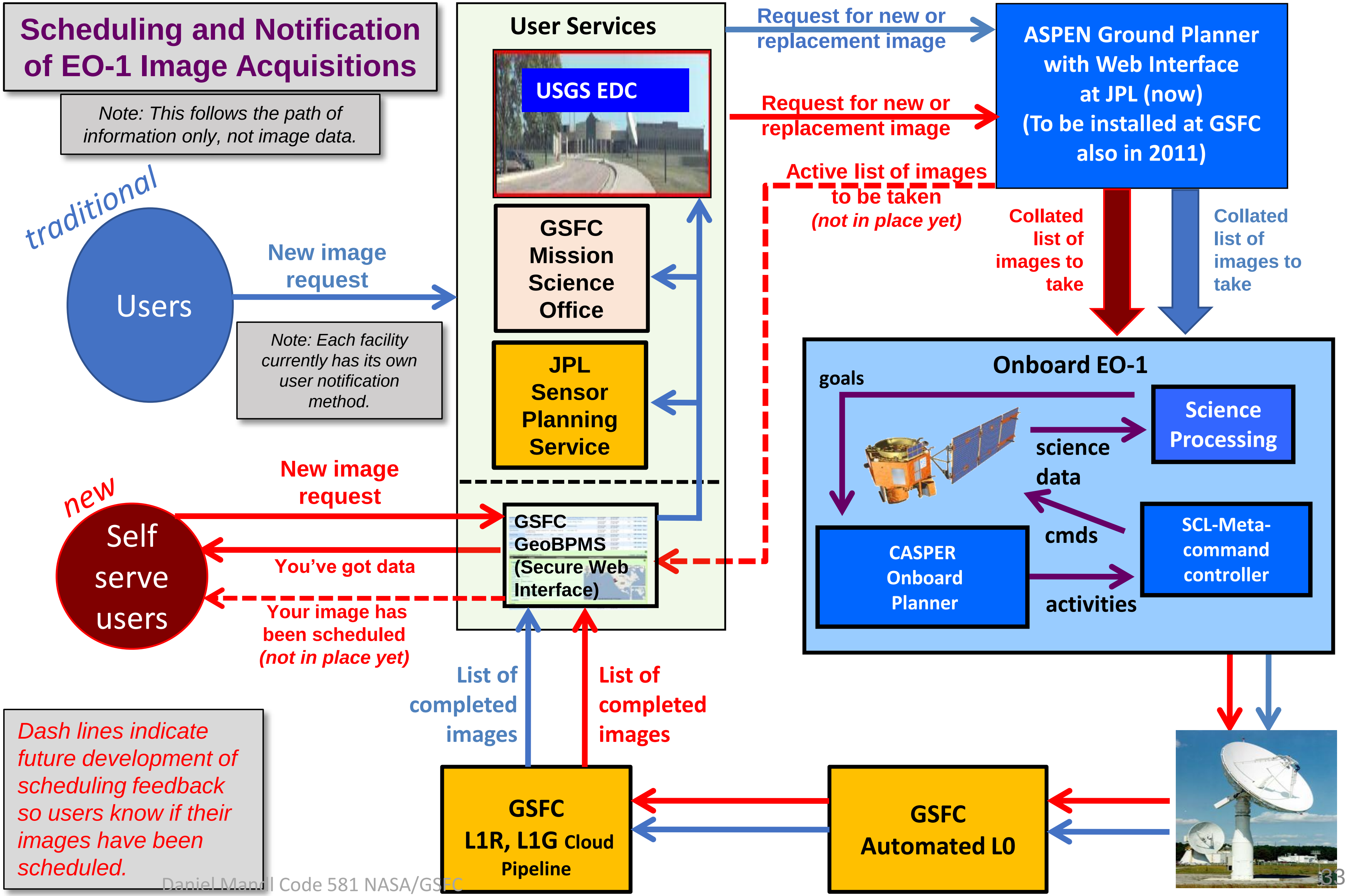
Title:	California
Description:	
Category:	
Latitude:	41.3
Longitude:	-123.8
Country Code:	US
Country Name:	United States
Zone Number:	36
Zone Name:	Northern California
Region Number:	3
Region Name:	Oregon, California and Nevada
Admin Code:	CA
Admin Name:	California
Nearby:	Notchko, Surgone, Shregegon (historical), Mettah, Pekwan (historical), Pecwan, Johnsons, Waseck, Wright Place, Martins Ferry (historical)
Created At:	Fri, 19 Sep 2008 02:32:22 -0000
Updated At:	2008-09-19

GeoBliki User Interface

1 Found

USAFRICOM	USAFRICOM Testing	flooding	cappelaere	Zimbabwe	06/19/2008 02:58 PM	06/19/2008 02:58 PM	-	Edit Delete Show

Problem was that there were too many Legacy Pipes and it took a while to cobble custom notification alerts from various systems



Scheduling and Notification of EO-1 Image Acquisitions

Note: This follows the path of information only, not image data.

traditional

Users

New image request

Note: Each facility currently has its own user notification method.

new

Self serve users

New image request

You've got data

Your image has been scheduled *(not in place yet)*

User Services

USGS EDC

GSFC Mission Science Office

JPL Sensor Planning Service

GSFC GeoBPMS (Secure Web Interface)

Request for new or replacement image

Request for new or replacement image

Active list of images to be taken *(not in place yet)*

ASPEN Ground Planner with Web Interface at JPL (now) (To be installed at GSFC also in 2011)

Collated list of images to take

Collated list of images to take

Onboard EO-1

goals

science data

Science Processing

cmds

CASPER Onboard Planner

SCL-Meta-command controller

activities

List of completed images

List of completed images

GSFC L1R, L1G Cloud Pipeline

GSFC Automated L0

Dash lines indicate future development of scheduling feedback so users know if their images have been scheduled.

Solution

- If every node in a spacecraft or multi-spacecraft architecture writes status to an immutable block that is sync’ed every few minutes and is trusted, the only place users and systems have to go is the block
- Blockchain holds the history of all transactions
- Any new user only needs access to the block to get status and history
- Automatic easy extensibility for any system
- Previous example is just a single spacecraft, problem quickly becomes unmanageable with constellation

Blockchain Components

Blockchain

Ledger — contains the current world state of the ledger and a Blockchain of transaction invocations

Smart Contract — encapsulates business network transactions in code. transaction invocations result in gets and sets of ledger state

Consensus Network — a collection of network data and processing peers forming a Blockchain network. Responsible for maintaining a consistently replicated ledger

Membership — manages identity and transaction certificates, as well as other aspects of permissioned access

Events — creates notifications of significant operations on the Blockchain (e.g. a new block), as well as notifications related to smart contracts. Does not include event distribution.

Systems Management — provides the ability to create, change and monitor Blockchain components

Wallet — securely manages a user's security credentials

Systems Integration — responsible for integrating Blockchain bi-directionally with external systems. Not part of Blockchain, but used with it.

Public, Consortium, Private Blockchains

- **Public blockchains**: a public blockchain is a blockchain that anyone in the world can read, anyone in the world can send transactions to and expect to see them included if they are valid, and anyone in the world can participate in the ***consensus process*** – the process for determining what blocks get added to the chain and what the current state is. As a substitute for centralized or quasi-centralized trust, public blockchains are secured by cryptoeconomics – the combination of economic incentives and cryptographic verification using mechanisms such as proof of work or proof of stake, following a general principle that the degree to which someone can have an influence in the consensus process is proportional to the quantity of economic resources that they can bring to bear. These blockchains are generally considered to be "fully decentralized".
- **Consortium blockchains**: a consortium blockchain is a blockchain where the consensus process is controlled by a pre-selected set of nodes; for example, one might imagine a consortium of 15 financial institutions, each of which operates a node and of which 10 must sign every block in order for the block to be valid. The right to read the blockchain may be public, or restricted to the participants, and there are also hybrid routes such as the root hashes of the blocks being public together with an API that allows members of the public to make a limited number of queries and get back cryptographic proofs of some parts of the blockchain state. These blockchains may be considered "partially decentralized".
- **Fully private blockchains**: a fully private blockchain is a blockchain where write permissions are kept centralized to one organization. Read permissions may be public or restricted to an arbitrary extent. Likely applications include database management, auditing, etc internal to a single company, and so public readability may not be necessary in many cases at all, though in other cases public auditability is desired.

Source: https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/